

Introduction to NIF

Potential applicants to the Discovery Science call for proposals

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NIF User Office



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Outline

- Laser capability
- Target fabrication
- Target diagnostics
- Scheduling constraints

NIF is the world's largest, highest-energy,
highest-power laser: 1.86MJ — 523TW

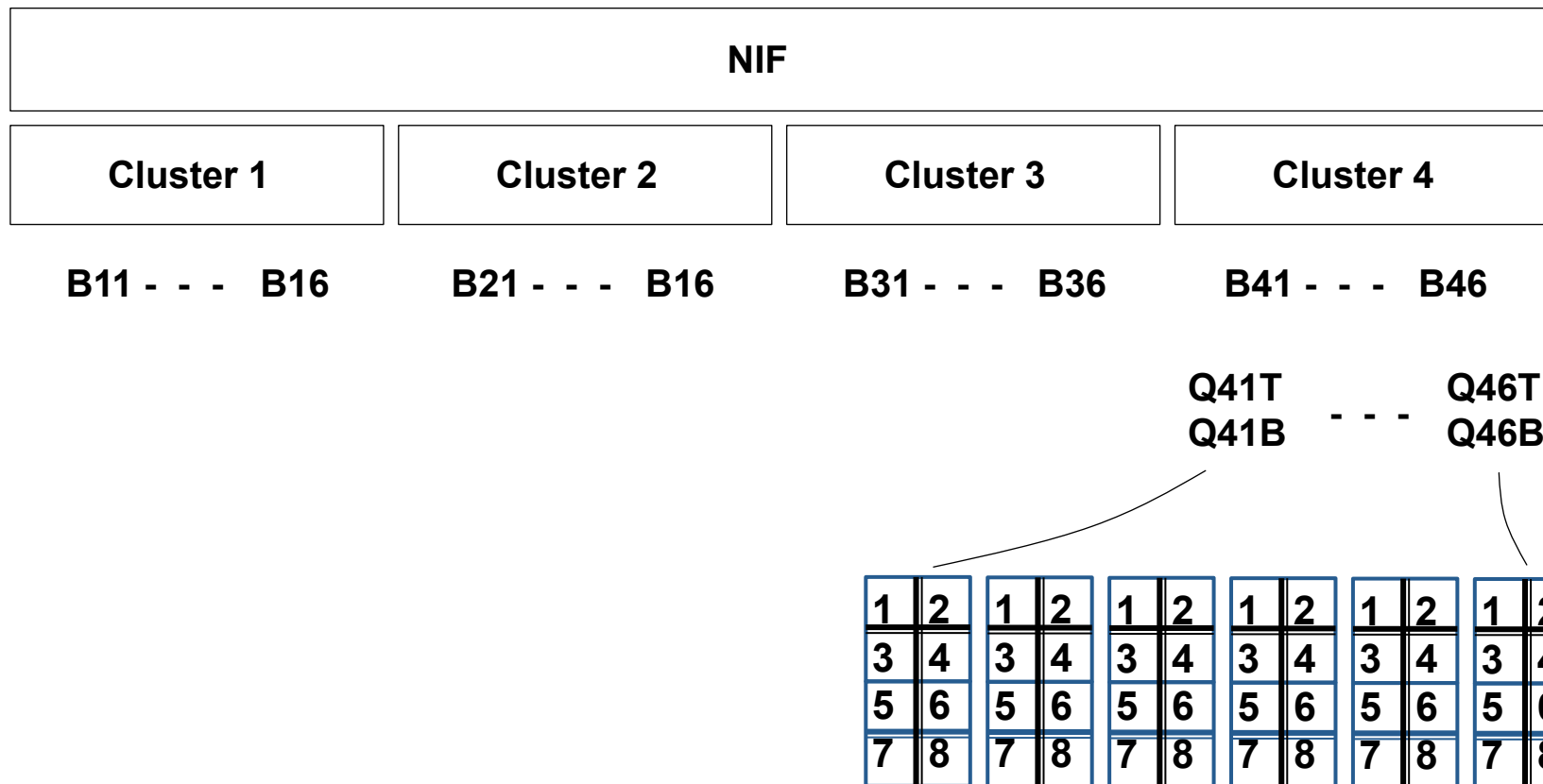


Laser performance

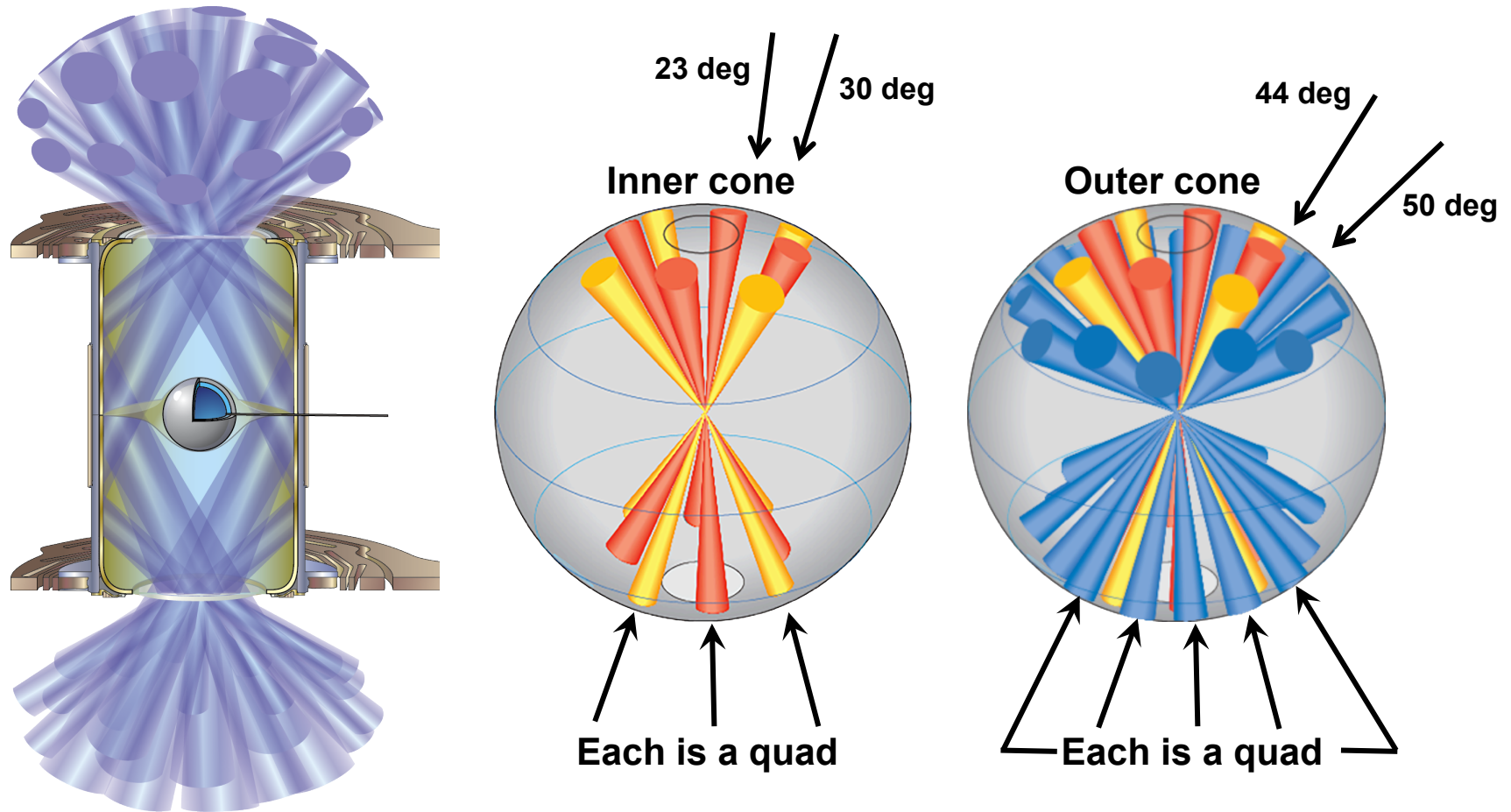
- NIF is a 192 beam laser designed to reliably deliver high power and energy to target to enable precision experiments
- Operation of the laser incorporates a living model of individual beam performance that is calibrated and adjusted to predict pulse shape delivery on individual shots to meet power balance and accuracy requirements
- Expert groups maintain reliable operation of the laser through review, planning and tracking of experiment impacts (machine safety) and performance
- NIF has a strategy of optics inspection and maintenance that allows it to operate “above the damage threshold” in a sustainable manner
- Operating below the damage threshold allows for more routine operation with a rapid shot cycle

Configuration

- NIF beams are grouped as clusters, bundles, quads, and beams
- Pulse shape, and timing are per quad, but timing with bundle limitations
- Energy is per beam, but with bundle limitations
- Pointing is per beam



The beams are grouped in inner and outer cones distinguished by polar angle



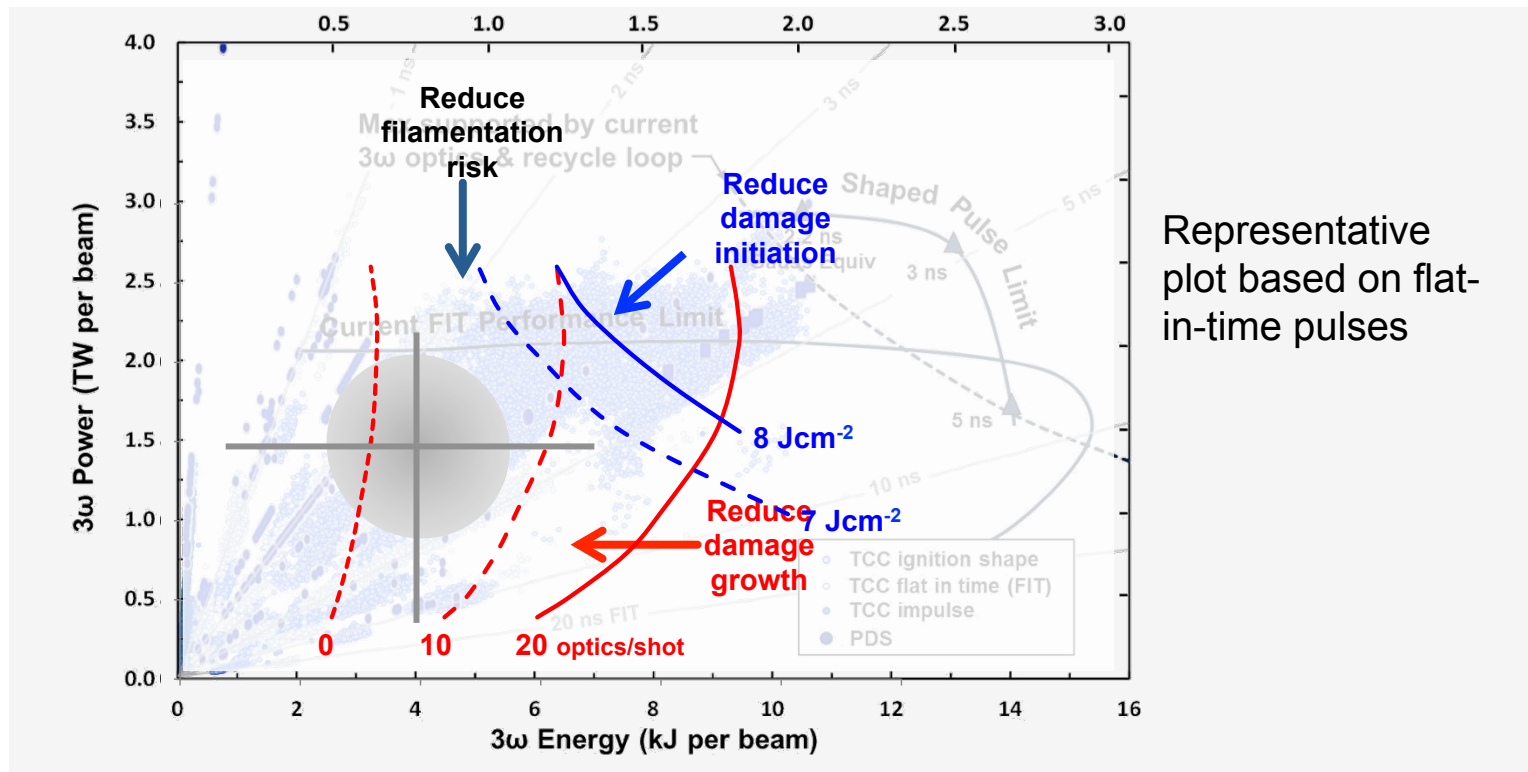
Groups of 4 beams (Quads) share some hardware and pulse shape capability → NIF is essentially 48 Quads each with 4 Beams

Pulse shape and energy

- Pulse shape
 - 88 ps impulse
 - >600 ps shaped pulses
 - 30 ns maximum pulse width
 - 100 ps rise at the beginning/end of the pulse, 600 ps transitions internal to the pulse shape
- Pulse timing
 - Flexible pulse delays – but actual ranges depend on energetics and power
 - Generally up to 30 ns delay available
 - Longer delays require fibers – additional planning and setup time during the shot
 - Timing is limited between quads in the same bundle
- Energy
 - There are power and energy limits associated with beam filamentation, and optics damage initiation and growth
 - 88 ps is limited to 56 J/beam
 - 3.3 ns square can be used at <4 kJ/beam
 - Shaped ignition pulses can be run at ~4 kJ/beam (800 kJ NIF) with minimal impact

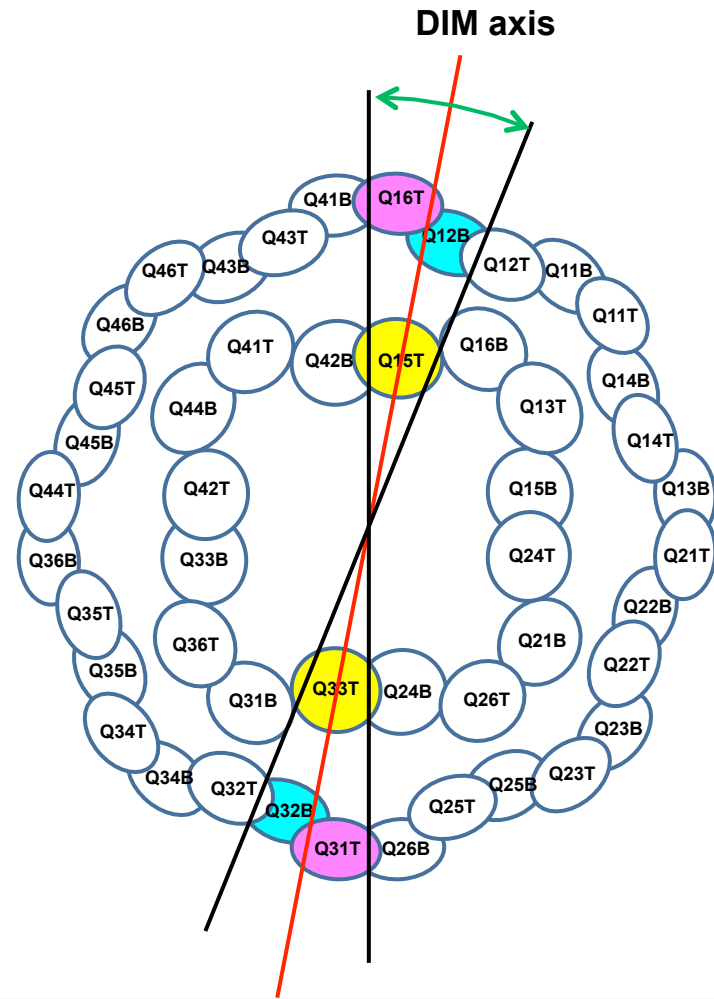
The NIF laser performance limits are driven by optics damage and non-linear effects

- NIF is capable of 1.8 MJ operation with a high-contrast shaped pulse
- Operation at this level exceeds the initiation and damage threshold for the NIF final optics (effectively uses up optics)
- Operation in a moderate power/energy space reduces the impact and allows for more shots



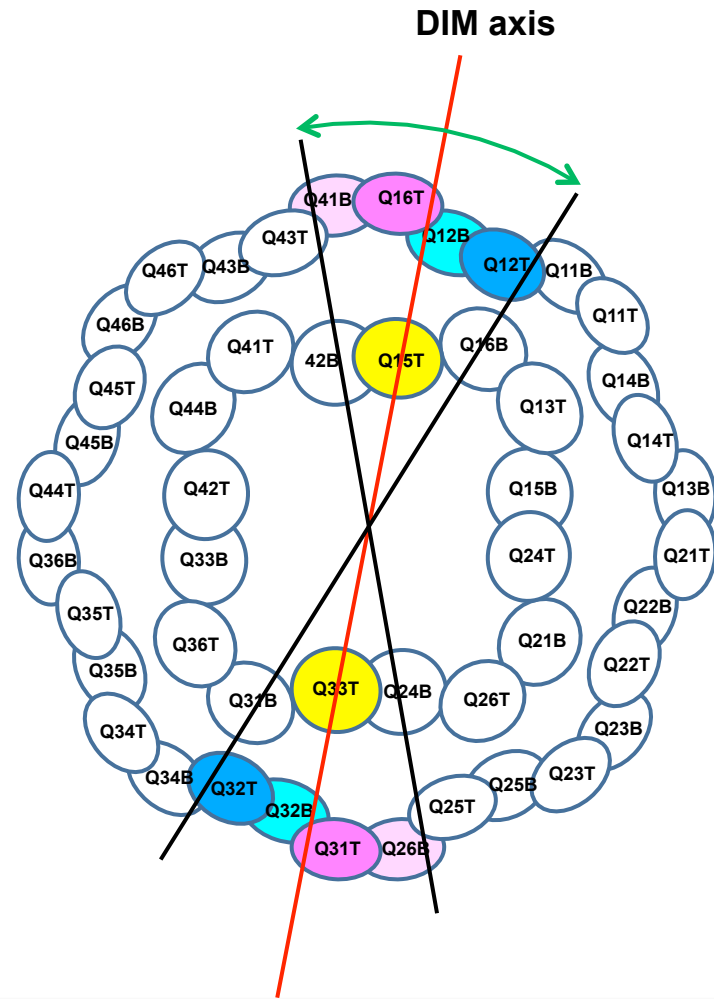
Beam pointing

- Beam pointing is currently limited to ± 5 mm left/right and ± 30 mm up/down wrt TCC (beam perspective)
 - There are individual limits per beamline
- Beam pointing limits affect the achievable standoff for backlighters
- Example: quads available for backlighting along the 90-78 DIM axis:
 - 6 quads can reach 34 mm offset



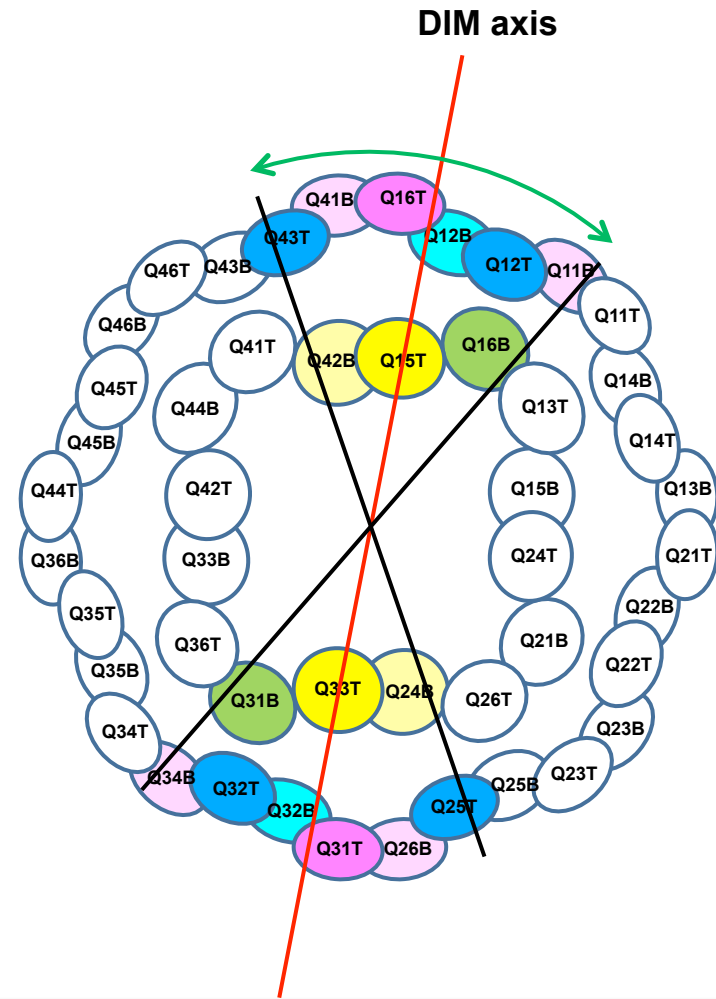
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- Example: quads available for backlighting along the 90-78 DIM axis:
 - 6 quads can reach 34 mm offset
 - 10 quads can reach 14.9 mm offset



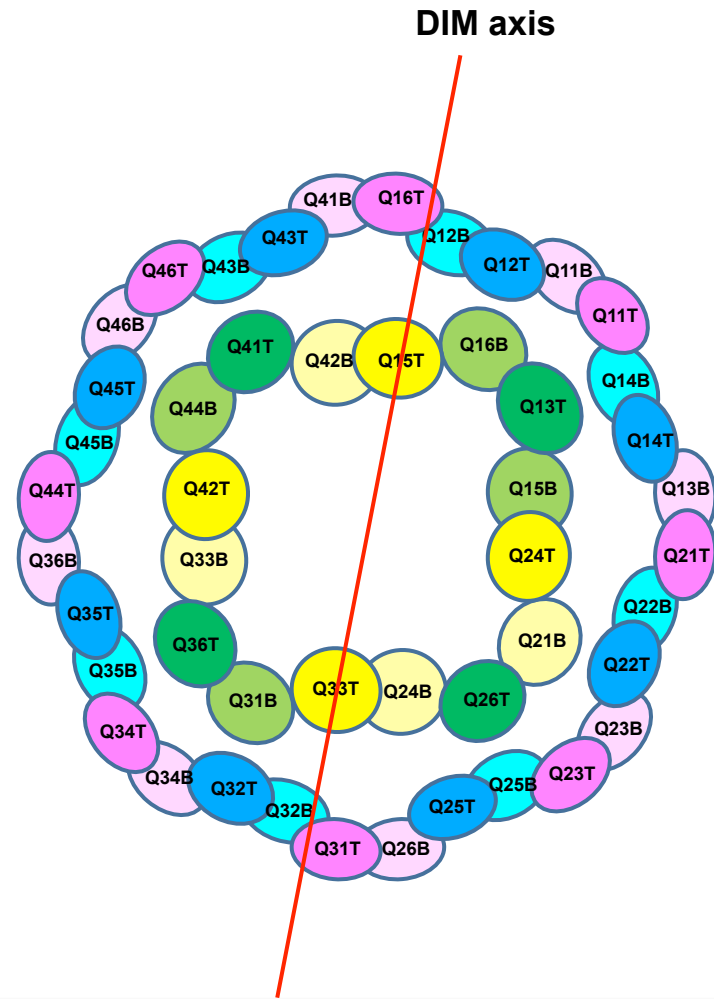
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 - 18 quads can reach 9.7 mm offset



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- Example: quads available for backlighting along the 90-78 DIM axis:
 - 6 quads can reach 34 mm offset
 - 10 quads can reach 14.9 mm offset
 - 18 quads can reach 9.7 mm offset
 - 48 quads can reach 5 mm offset



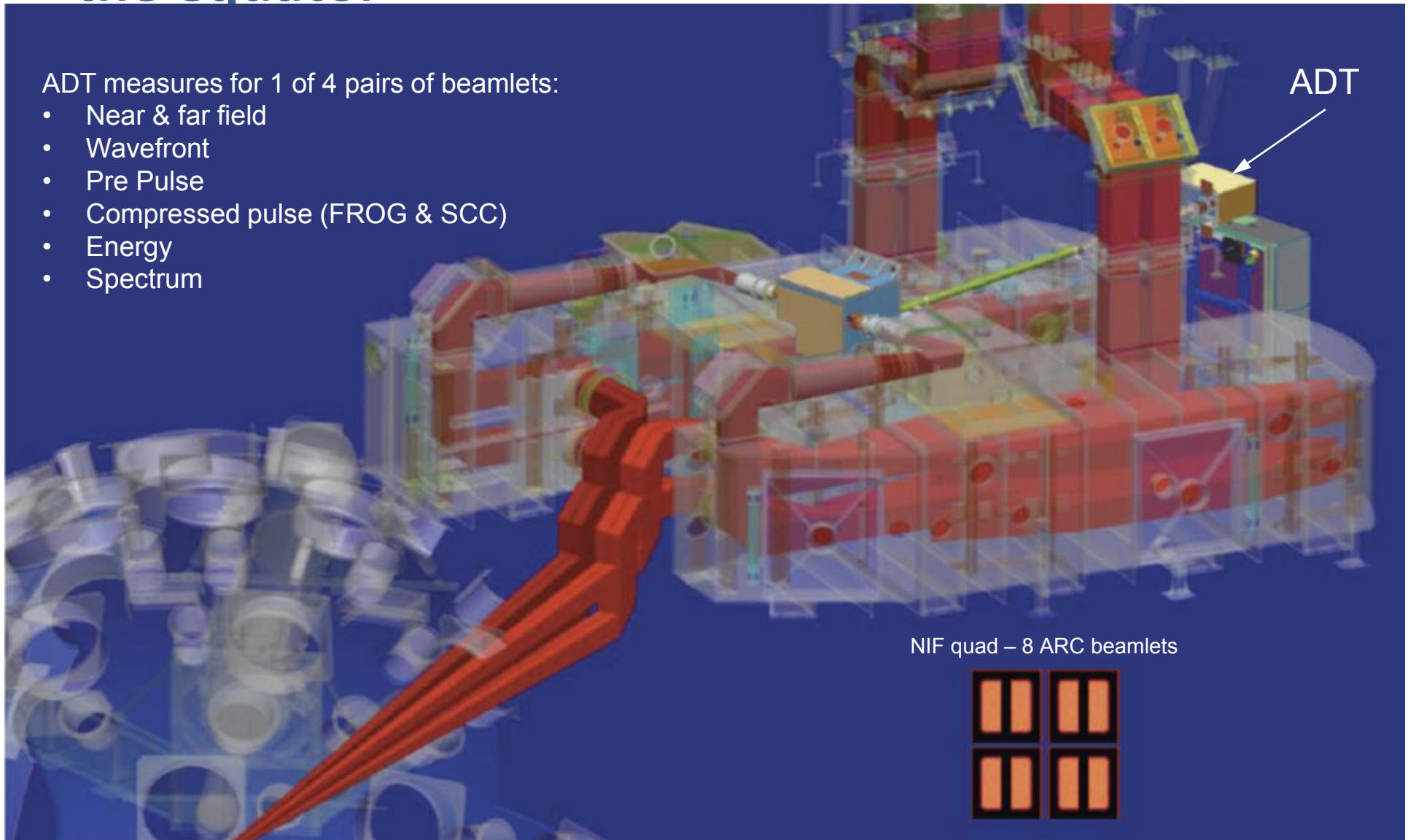
ARC has been commissioned with 30 ps pulses

- 1 NIF quad (35T) may be used in a short pulse mode (ARC)
 - 2 beams are each split into 2 beamlets
- 30 ps impulse with an expected energy of approximately 1200 J/beamlet
 - Shorter pulses (expected <3 ps) will be commissioned at lower energies
- Relative beamlet pointing and timing are limited
 - Co-pointing beamlets from the same beamline is ok over the nominal NIF pointing volume
- Front end contrast is approximately 80 dB

ARC beams come from port (77, 204) – above the equator

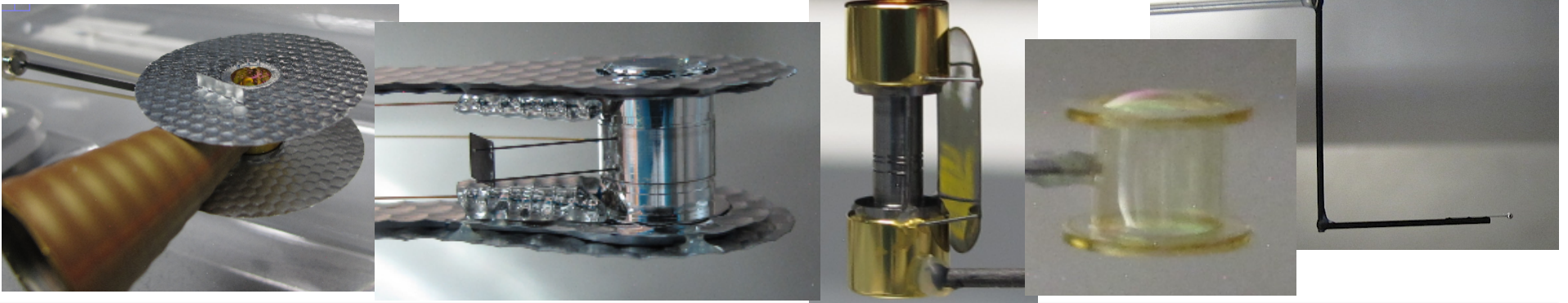
ADT measures for 1 of 4 pairs of beamlets:

- Near & far field
- Wavefront
- Pre Pulse
- Compressed pulse (FROG & SCC)
- Energy
- Spectrum



Targets

- Target fabrication support is provided by the LLNL target fab team
 - Target requests in successful proposals will be evaluated in light of current fabrication capability and budget
- Capabilities:
 - Hohlraum
 - Direct drive foils
 - Gas pipes
 - Shock tube
- Targets based on existing experimental platforms will streamline the review process and subsequent fabrication

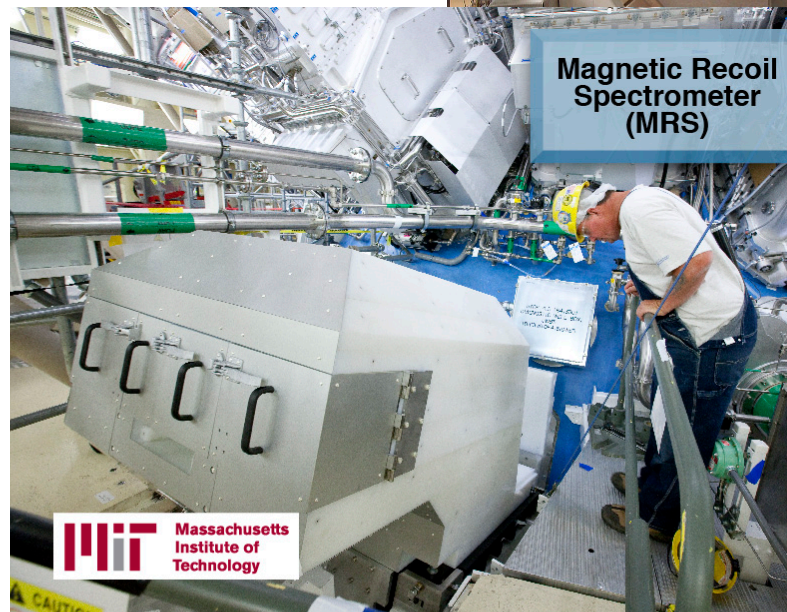
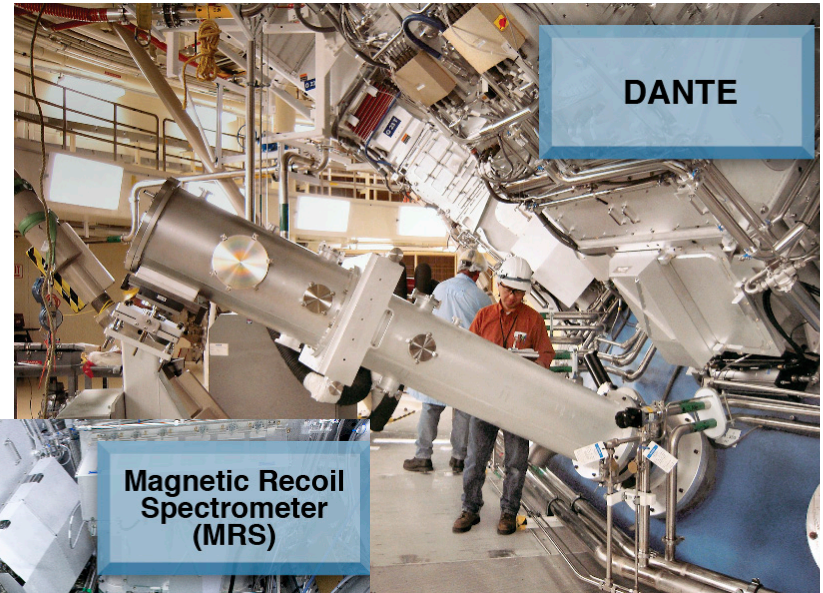


Target chamber

- The NIF chamber is 10 m in diameter, maintained at high vacuum
- 3 target positioners available:
 - C-TARPOS for cryo-layering, TARPOS with cold capability, TanDM for warm targets only
 - Positioner use may be identified for efficiency and rapid shot turn-around
- 3 DIM lines of sight for insertable diagnostic access to view the target
 - 1 TanDM line of sight provides an optional additional diagnostic location
- Target, diagnostic snouts, and filters are routinely exchanged or refurbished on each shot
 - Re-use requires review
- The number of diagnostic transactions between experiments impacts the overall shot cycle duration

Diagnostics

- X-ray
 - Fixed – Dante, FFLEX, SXI, DIXI, SPIDER
 - DIM-based – streaked and gated imagers with pinhole and spectrometer snouts
 - X-ray bang time
- Optical
 - FABS/NBI
 - VISAR
 - OTS
- Nuclear
 - Yield
 - NToF
 - MRS
 - Neutron imaging
 - Neutron bang time



Examples

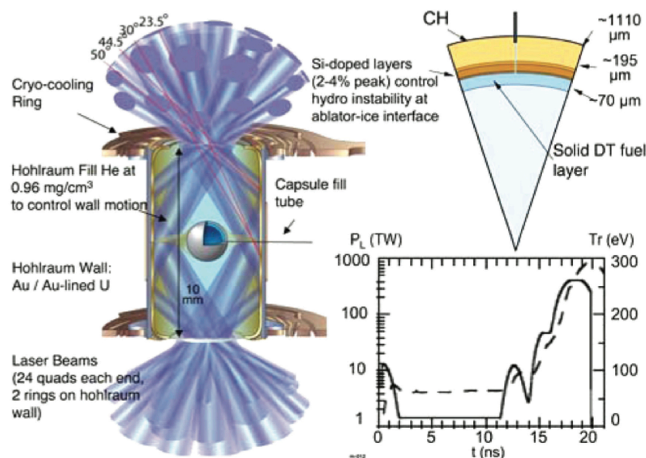
- Implosion core imaging
 - 12X with 0.25 mm field of view (before overlapping images)
 - 4-7.8X imaging with 1-1.5 mm field of view for in-flight imaging
 - 2X with 3 mm field of view for early-time capsule drive symmetry
- Backlighting
 - 1-4X imaging with larger field of view
- Spectroscopy
 - Wavelength coverage capability at 0.5-18 keV
 - Energy resolution of $E/dE \sim 100-700$

Ignition implosion platform

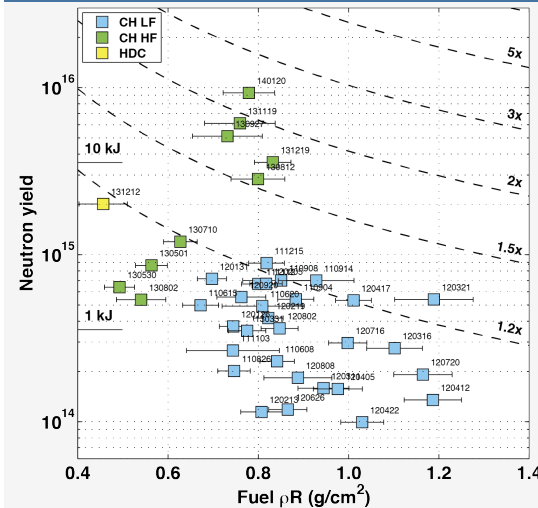
https://lasers.llnl.gov/content/assets/docs/for-users/platforms_indirect_direct_drive.pdf

- Layered DT ignition capsules
 - Contain solid cryogenic DT fuel layers
 - Designed to ignite and burn producing $\sim 10\text{-}20$ MJ of energy

Schematic of NIF ignition target, capsule and a typical laser pulse (solid line) and resulting simulated X-ray drive (dashed line)



Total neutron yield vs. fuel ρR for all cryogenic layered implosions on the NIF



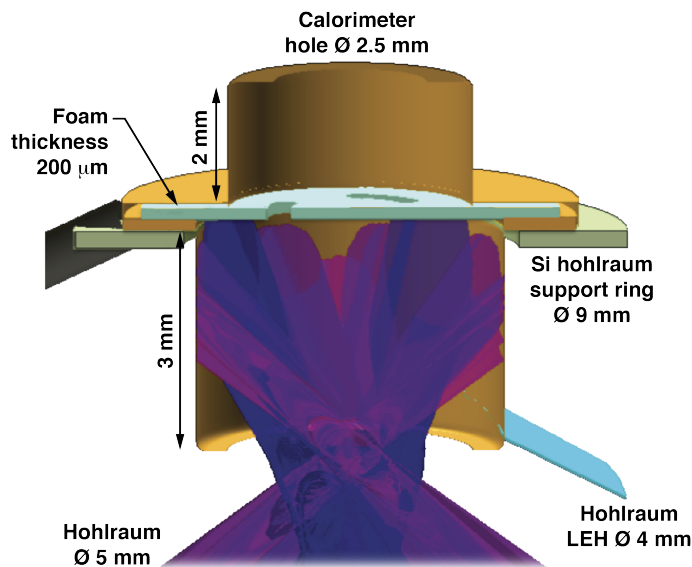
Current conditions achieved

- High $Y_n \sim 10^{14}\text{-}10^{16}$
- Rapid burn $\sim 50\text{-}100$ ps
- Burn avg temp ~ 5 keV
- Burn avg density $\sim 150\text{-}300 \text{ g/cm}^3$

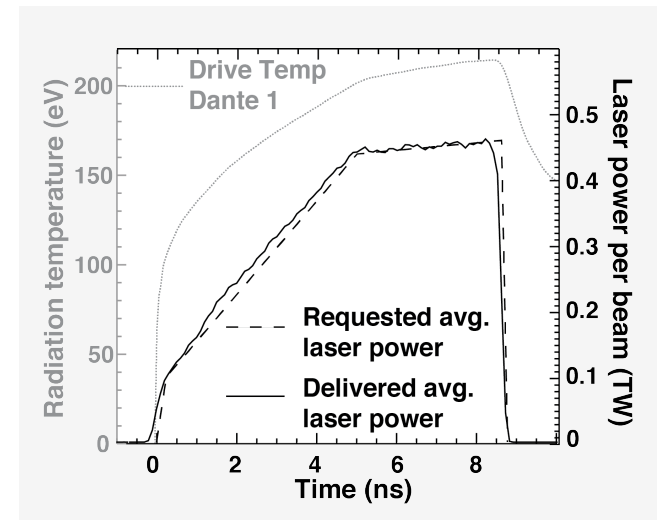
Half-hohlraums

https://lasers.llnl.gov/content/assets/docs/for-users/platforms_half_hohlraum.pdf

- Half-hohlraum provides capability for radiation driven samples placed on the axis for hydrodynamics and radiation flow experiments
- Subsonic Radiation Transport
 - Subsonic Radiation Transport experiments study the evolution of an “N-wave” density structure in slots cut into a Ta_2O_5 aerogel



- A large 4.0 mm diameter half-hohlraum, driven by 80 lower quads, creates a power-law-in-time x-ray drive over 9.0-12.0 ns with a 200-240 eV peak temperature
- The x-ray drive launches a shock followed by a subsonic Marshak wave in the aerogel
- Slots machined in the aerogel evolve into an “N-wave” density profile

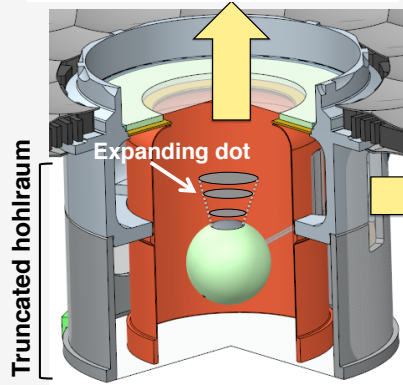
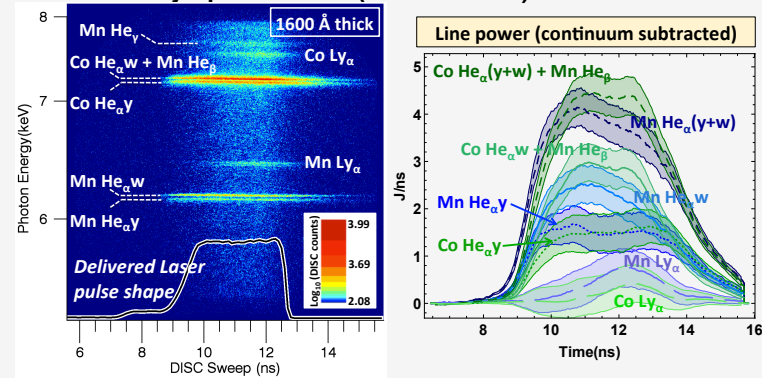


Half-hohlraums – spectroscopy application

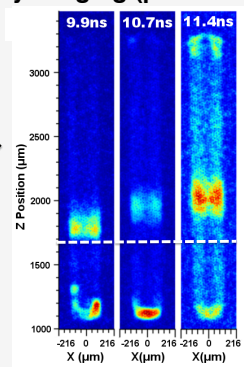
- Multiple lines of sight are available for spectroscopy measurements and x-ray imaging

- see M. A. Barrios *et al.*, Physics of Plasmas **23**, 056307 (2016)

Streaked X-ray Spectrometer (line emission)



X-ray imaging (plasma flow)



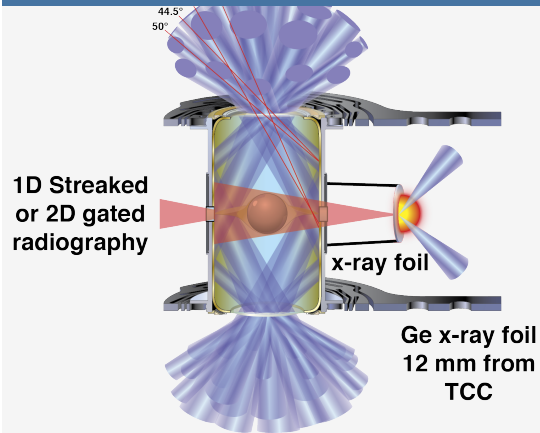
- Mn:Co or Mn only dot on CH shell
- Dot material gets hot and emits; measured line emission is used as T_e diagnostic.
- Side slit provides dot trajectory and expansion

- Local measurements of electron temperature and target expansion
 - Spectroscopic tracers introduced to a capsule; line ratios exhibit strong temperature-dependent trends
 - Imagers through viewing slots allow measurement of plasma flows
- NIF provides a modest set of spectrometers for user experiments
- NIF provides a variety of x-ray imagers, both x-ray framing cameras and streak cameras

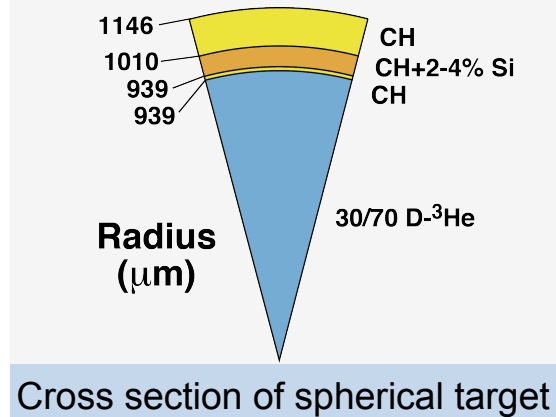
Radiography platforms

https://lasers.llnl.gov/content/assets/docs/for-users/platforms_horizontal_vertical_axis_radiography.pdf

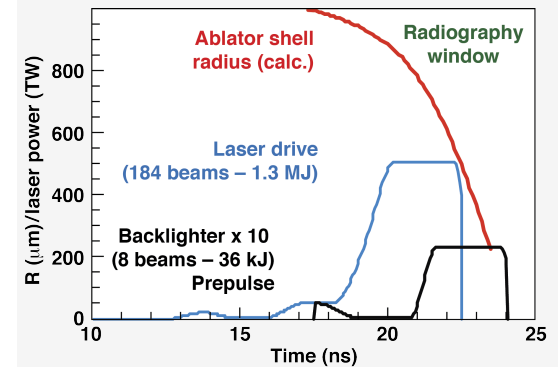
Experimental setup



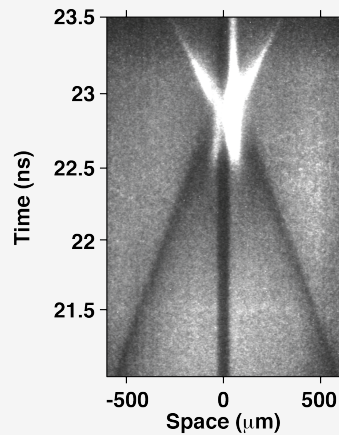
Symcap target



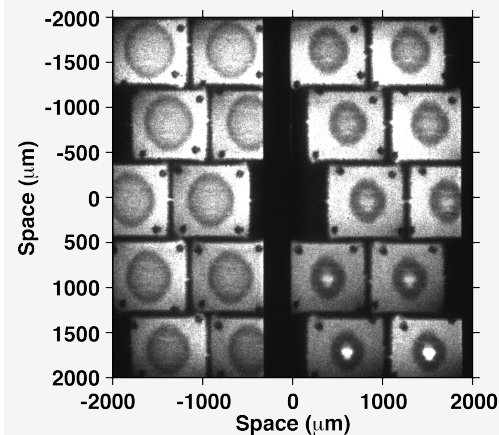
Laser pulse shape



1D equatorial radiograph



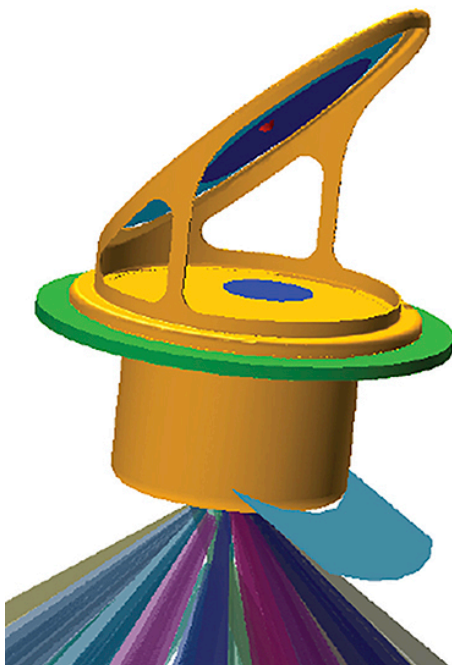
2D equatorial radiograph



Shock timing and equation of state

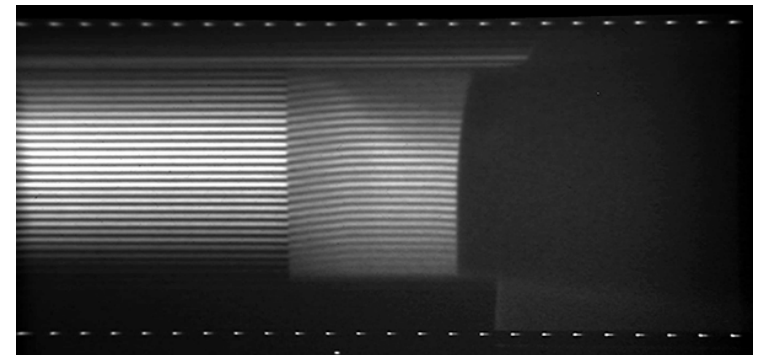
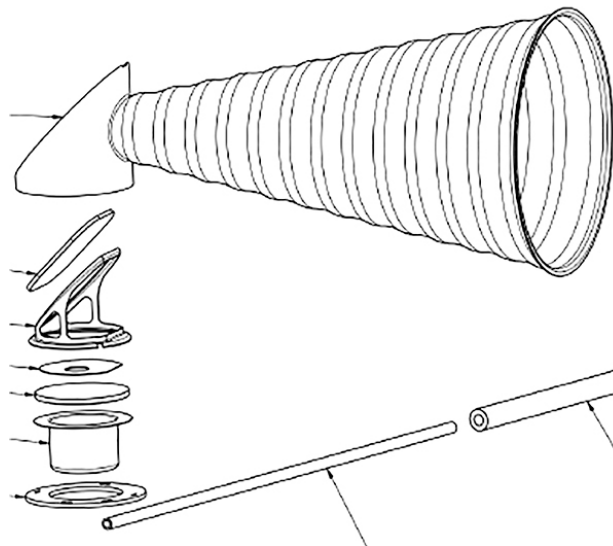
https://lasers.llnl.gov/content/assets/docs/for-users/platforms_shock_timing_eos.pdf

- Example shock timing measurement from a planar foil driven by a half hohlraum x-ray drive
- VISAR view of the target is achieved with a fold mirror mounted on the target



- Warm target
- Vacuum hohlraum

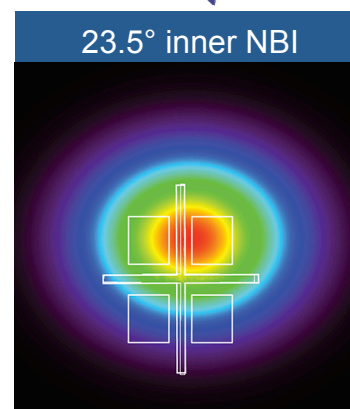
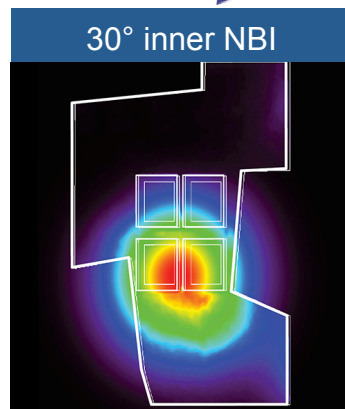
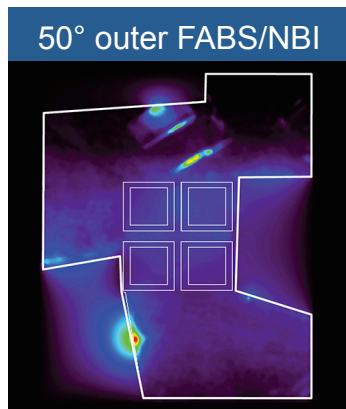
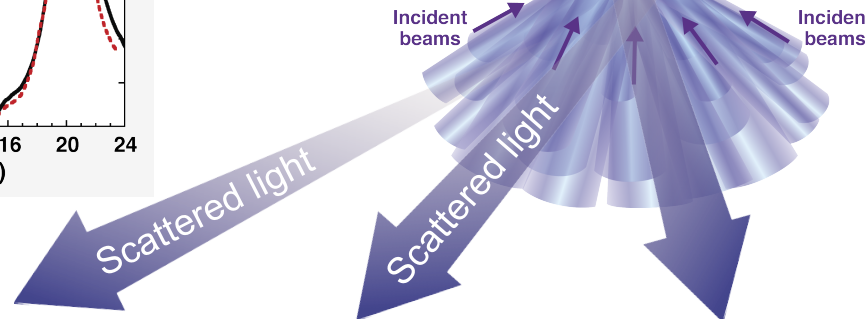
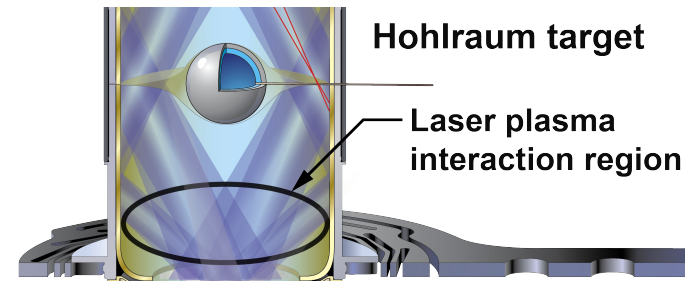
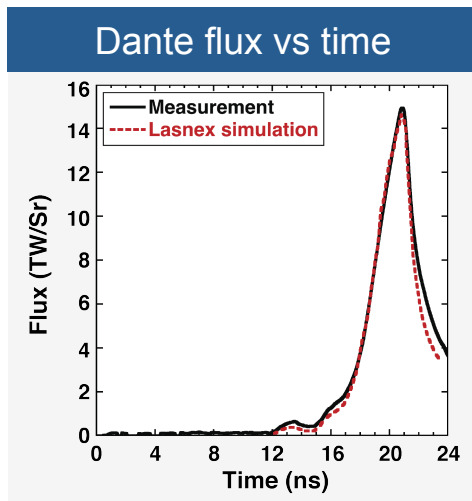
- Mirror requires a shield cone to protect it from scattered and unconverted light



- Compatible with additional x-ray diagnostics
 - Backlit radiography
 - X-ray Thomson scattering

Laser plasma interactions

https://lasers.llnl.gov/content/assets/docs/for-users/platforms_lpi.pdf



Optical scatter measurement capabilities	
Backscatter level	Required accuracy
25%	15%
10%	20%
2%	50%
<ul style="list-style-type: none"> • 200 ps time resolution • 5 nm SRS: 0.3 Å SBS 	

Scheduling

- NIF schedule process
 - Identify a 'train schedule' based on common diagnostic configurations
 - Assign campaigns and shots into the schedule based on the assigned configuration
- Successful proposals will be awarded time
- Allocation of time may be effectively used by matching existing configurations and minimizing CPP transactions and red-line laser performance requirements
 - Typical shot cycle today is 8-12 hrs
- Requirements for new capabilities drives scheduling
 - There is a separate process to propose new major capabilities
 - Engineering to support new capability must be coordinated with facility scheduling
- There is a minimum set of information to assess and schedule experiments
 - Energy/ peak power/ lines of sight/ cryo vs warm/ CPPs/ diagnostic selection

Other constraints and comments

- Configuration
 - Unconverted light has to be managed to prevent reflections from flat target surfaces that could damage the laser
- Review process
 - There is a detailed review process to ensure that experiments can be safely executed
- Resources (<https://lasers.llnl.gov/for-users>)
 - Once a campaign is approved and allocated time on NIF we provide assistance through the NIF User Office
 - NIF User guide, shot RI training, points of contact list, other documentation
 - Liaison scientist if requested
 - Project engineer to facilitate readiness
 - Senior scientist technical support



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